

Magnetospheric Substorms and Tail Dynamics

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I. Summary of Research:

This grant funded several studies of magnetospheric substorms and their effect on the dynamics of the earth's geomagnetic tail.

We completed an extensive study of plasmoids, plasma/magnetic field structures that travel rapidly down the tail, using data from the ISEE 3 and IMP 8 spacecraft. This study formed the PhD thesis of Mark Moldwin. We found that magnetically plasmoids are better described as flux-ropes (twisted magnetic flux tubes) rather than plasma bubbles, as had been generally regarded up to that point (Moldwin and Hughes, 1990; 1991). We published several examples of plasmoids observed first in the near tail by IMP 8 and later in the distant tail by ISEE 3, confirming their velocities down tail (Moldwin and Hughes, 1992a). We showed how the passage of plasmoids distorts the plasma sheet (Moldwin and Hughes, 1992b). We completed the first extensive statistical survey of plasmoids (Moldwin and Hughes, 1992c) that showed how plasmoids evolve as they move down tail from their formation around 30 R_E to ISEE 3 apogee at 240 R_E . We established a one-to-one correspondance between the observation of plasmoids in the distant tail and substorm onsets at earth or in the near tail (Moldwin and Hughes, 1993). And we showed that there is a class of plasmoid-like structures that move slowly earthward, especially following weak substorms during northward IMF (Moldwin and Hughes, 1994). Collectively this work constituted the most extensive study of plasmoids prior to the work that has now been done with the GEOTAIL spacecraft.

Following our work on plasmoids, we turned our attention to signatures of substorm onset observed in the inner magnetosphere near geosynchronous orbit, especially signatures observed by the CRRES satellite (Singer et al., 1993, Maynard et al., 1996). Using data from the magnetometer, electric field probe, plasma wave instrument, and low energy plasma instrument on CRRES we were able to better document substorm onsets in the inner magnetosphere than had been possible previously. Detailed calculation of the Poynting flux showed energy exchange between the magnetosphere and ionosphere, and a short burst of tailward convective flow just prior to onset, suggesting the active role of the ionosphere in the onset process, and adding credibility to the ballooning instability theory of substorm onset.

This grant also supported a number of other substorm studies and reviews. These are represented by the list of publications and meeting presentations resulting out of this grant.

II. Inventions: No inventions resulted from this grant.

III. Publications:

Published Papers

- Slavin, J.A., Baker, D.N., Craven, J.D., Elphic, R.C., Fairfield, D.H., Frank, L.A., Galvin, A.B., Hughes, W.J., Manka, R.H., Mitchel, D.G., Richardson, I.G., Sanderson, T.R., Sibeck, D.J., Smith, E.J., and R.D. Zwickl, CDAW 8 observations of plasmoid signatures in the geomagnetic tail: An assessment, *J. Geophys. Res.*, *94*, 15153, 1989.
- Kivelson, M.G., and Hughes, W.J., On the threshold for triggering substorms, *Planet. Space Sci.*, *38*, 211, 1990.
- Moldwin, M.B. and Hughes, W.J., A $2\frac{1}{2}$ dimensional magnetic field model of plasmoids, in the *The Physics of Magnetic Flux Ropes*, (C.T. Russell, E.R. Priest and L.C. Lee, eds.), AGU Mono. Ser., v58, p. 663, American Geophysical Union, Washington, DC, 1990.
- Moldwin, M.B., and Hughes, W.J., Plasmoids as magnetic flux ropes, *J. Geophys. Res.*, *96*, 14051, 1991.
- Moldwin, M.B., and Hughes, W.J., Multisatellite observations of plasmoids: IMP 8 and ISEE 3, *Geophys. Res. Lett.*, *19*, 1081, 1992a.
- Moldwin, M.B., and Hughes, W.J., Plasmoid observations in the distant plasma sheet boundary layer, *Geophys. Res. Lett.*, *19*, 1911, 1992b.
- Moldwin, M.B., and Hughes, W.J., On the formation and evolution of plasmoids: a survey of ISEE 3 Geotail data, *J. Geophys. Res.*, *97*, 19259, 1992c.
- Singer, H.J., Hughes, W.J., and Anderson, R.R., Advances in substorm physics from CRRES, *Adv. Space Res.*, *13*, (4)203, 1993.
- Moldwin, M.B., and Hughes, W.J., Geomagnetic substorm association of plasmoids, *J. Geophys. Res.*, *98*, 81, 1993.
- Hughes, W.J., (Editor), *Outstanding Questions in Geotail and Substorm Physics*, Report of the GEM Workshop on the Physics of the Tail and Substorms. Boston University, May 1993.
- Moldwin, M.B., and Hughes, W.J., Observations of earthward and tailward propagating flux rope plasmoids: Expanding the plasmoid model of geomagnetic substorms, *J. Geophys. Res.*, *99*, 183, 1994.
- Hughes, W.J., (Editor), *Strategies for the Tail and Substorm Campaign*, Report of the GEM Workshop on the Physics of the Tail and Substorms. Boston University, April 1994.
- Hughes, W.J., The Magnetopause, Magnetotail, and Magnetic Reconnection, in *Introduction to Space Physics* (M.G. Kivelson and C.T. Russell, Eds), pp 227-287, Camb. Univ. Press., New York, 1995.
- Angelopoulos, V., D.G. Mitchell, D.J. Williams, R.W. McEntire, A.T.Y. Lui, R.B. Decker, S.M. Krimigis, E.C. Roelof, S.P. Christon, S. Kokubun, T. Yamamoto, W.J. Hughes, J.C. Samson, E. Friis-Christensen, and K. Hayashi, Growth and Evolution of a Plasmoid Associated with a Small, Isolated Substorm: IMP8 and GEOTAIL Measurements in the Magnetotail, *Geophys. Res. Lett.*, *22*, 3011, 1995.
- Maynard, N.C., W.J. Burke, E.M. Basinska, G.M. Erickson, W.J. Hughes, H.J. Singer, A. Yahnin, D.A. Hardy, and F.S. Mozer, Dynamics of the inner magnetosphere near times

of substorm onsets, *J. Geophys. Res.*, **101**, 7705, 1996.

- Angelopoulos, V., A.T.Y. Lui, R.W. McEntire, D.J. Williams, S.P. Christon, M. Nakamura, H. Kusaka, T. Mukai, S. Kokubun, T. Yamamoto, G.D. Reeves, E. Friis-Christensen, and W.J. Hughes, Anisotropy reversals in the distant magnetotail and their association with magnetospheric substorms, *J. Geomag. Geoelectr.*, **48**, 629, 1996.
- Angelopoulos, V., D.G. Mitchell, R.W. McEntire, D.J. Williams, A.T.Y. Lui, S.M. Krimigis, R.B. Decker, S.P. Christon, S. Kokubun, T. Yamamoto, Y. Saito, T. Mukai, F.S. Mozer, K. Tsuruda, R. Lepping, G. Reeves, W.J. Hughes, E. Friis-Christensen, and O. Troshichev, Tailward progression of magnetotail acceleration centers: relationship to substorm current wedge, *J. Geophys. Res.*, **101**, 24599, 1996.
- Spence, H.E., A.M. Jorgensen, W.J. Hughes, J.F. Fennell, and J.L. Roeder, Towards Inner Magnetosphere Particle and Field Models, *Adv. Space Res.*, **20**, (3)427, 1997.

Invited Papers Presented at Meetings

- W.J. Hughes, Multisatellite Observations of Substorm Onsets, Invited Paper, MIT Annual Symposium on the Physics of Space Plasmas, January 25, 1990
- W.J. Hughes, Reconnection at the Magnetopause, Invited Lecture, 1990 Rubey Symposium, UCLA, March 26-30, 1990.
- W.J. Hughes, The Geomagnetic Tail, Invited Lecture, 1990 Rubey Symposium, UCLA, March 26-30, 1990.
- W.J. Hughes, Are There Flux Ropes in the Earth's Magnetosphere? Invited Paper, session on Plasmoids in Solar and Magnetospheric Plasmas, American Geophysical Union Spring Meeting, May, 1990. (Abstract: *EOS*, **71**, 608, 1990)
- W.J. Hughes, Waves and substorms observed on the CRRES satellite, Invited Paper, V-Finnish-US Auroral Workshop, Tervahovi, Finland, March 1992.

Papers Presented at Meetings

- M.B. Moldwin and W.J. Hughes, A $2\frac{1}{2}$ -dimensional magnetic field model of plasmoids, Chapman Conference on the Physics of Magnetic Flux Ropes, Bermuda, March 1989.
- M.G. Kivelson and W.J. Hughes, On the threshold for triggering substorms, American Geophysical Union Spring Meeting, Baltimore, May 1989. (Abstract: *EOS*, **70**, 445, 1989).
- M.G. Kivelson, W.J. Hughes and R.L. McPherron, Tail hinging and substorm onset, 6th IAGA Scientific Assembly, Exeter, UK, August 1989.
- W.J. Hughes and M.G. Kivelson, A test of the bent tail hypothesis of substorm triggering using the AL index, 6th IAGA Scientific Assembly, Exeter, UK, August 1989.

- M.B. Moldwin, and W.J. Hughes, Plasmoids as Magnetic Flux Ropes, Chapman Conference on Magnetospheric Substorms, Hakone, Japan, September 1990.
- M.B. Moldwin, and W.J. Hughes, A Study of Plasmoid Properties: Survey of ISEE 3 Geotail Data, American Geophysical Union Fall Meeting, San Francisco, December 1990. (Abstract: *EOS*, 71, 1548, 1990)
- W.J. Hughes, H.J. Singer, B.J. Fraser, M. Smiddy, and J.R. Wygant, Substorm onsets in the inner magnetosphere: CRRES observations, Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS*, 72, 248, 1991).
- M.B. Moldwin, and W.J. Hughes, The Evolution of Plasmoids: Survey of ISEE 3 Geotail Data, Spring American Geophysical Union Meeting, Baltimore, May 1991 (Abstract: *EOS*, 72, 242, 1991).
- M.B. Moldwin, and W.J. Hughes, The Formation and Evolution of Plasmoids: Survey of ISEE 3 Geotail Data, IUGG XX General Assembly, Vienna, August 1991.
- M.B. Moldwin, and W.J. Hughes, Multisatellite Observations of Plasmoids, American Geophysical Union Fall Meeting, San Francisco, December 1991, (Abstract: *EOS*, 72, 396, 1991).
- W.J. Hughes, H.J. Singer, J. Wygant, Multisatellite observations of substorm onsets in the inner magnetosphere, International Conference on Substorms, Kiruna, March 1992.
- H.J. Singer, W.J. Hughes, J. Wygant, R.R. Anderson, Substorm observations in the inner magnetosphere by CRRES, International Conference on Substorms, Kiruna, March 1992.
- M.B. Moldwin, and W.J. Hughes, Substorm associated bipolar events in the distant plasmasheet boundary layer and magnetosheath, American Geophysical Union Spring Meeting, Montreal, May 1992, (Abstract: *EOS*, 73, 269, 1992).
- M.B. Moldwin, and W.J. Hughes, Estimate of Plasma and Energy Loss via Plasmoids, 3rd Annual Huntsville Workshop, October 1992
- H.J. Singer, W.J. Hughes and R.R. Anderson, Substorms and auroral kilometric radiation: CRRES observations, American Geophysical Union Fall Meeting, San Francisco, December 1992 (Abstract: *EOS*, 73, 465, 1992)
- M.B. Moldwin, and W.J. Hughes, Earthward Propagating Flux Rope Plasmoids, American Geophysical Union Fall Meeting, San Francisco, December 1992 (Abstract: *EOS*, 73, 471, 1992)
- M. Moldwin, and W.J. Hughes, Expanding the plasmoid model of geomagnetic substorms, Second International Conference on Substorms, Fairbanks, Alaska, March 1994.
- W.J. Hughes, and H.J. Singer, Magnetic Field Reconfigurations Near Synchronous Orbit at Substorm Onset, American Geophysical Union Fall Meeting, San Francisco, December 1994, (Abstract: *EOS*, 75, Fall Meeting Supplement p.575, 1994).

- N.C. Maynard, G.M. Erickson, E.M. Basinska, W.J. Hughes, H.J. Singer, A. Yahnin, and F.S. Mozer, Substorm Onset at the Inner Edge of the Plasma Sheet, American Geophysical Union Spring Meeting, Baltimore, May 1995 (Abstract: *EOS*, 76, Spring Meeting Supplement p.261, 1995).
- V. Angelopoulos, D.G. Mitchell, R.W. McEntire, D., J. Williams, A.T.Y. Lui, S.P. Christon, S. Kokubun, T. Yamamoto, T. Mukai, Y. Saito, G. Reeves, W.J. Hughes, E. Friis-Christensen, and O. Troshichev, GEOTAIL/IMP8 Observations in the Magnetotail During the Course of a Substorm, American Geophysical Union Spring Meeting, Baltimore, May 1995 (Abstract: *EOS*, 76, Spring Meeting Supplement p.262, 1995).
- N.C. Maynard, W.J. Burke, D.A. Hardy, E.M. Basinska, G.M. Erickson, W.J. Hughes, H.J. Singer, A. Yahnin, and F.S. Mozer, Dynamics of the Inner Magnetosphere Near Substorm Onset, IUGG XXI General Assembly, Boulder, July 1995
- N. Cornilleau-Wehrlin and W.J. Hughes, Multipoint Study of Substorm Onset Signatures, Third International Conference on Substorms, Versailles, May 1996.
- J.L. Roeder, J.F. Fennell, H.E. Spence, and W.J. Hughes, Statistical Model of Energetic Ion Distribution Moments in the Inner Magnetosphere, American Geophysical Union Spring Meeting, Baltimore, May 1996. (Abstract: *EOS*, 77, S254, 1996)
- H.E. Spence, A.M. Jorgensen, W.J. Hughes, J.F. Fennell, and J.L. Roeder, Towards Inner Magnetosphere Particle and Field Models, XXXI COSPAR General Assembly, Birmingham, UK, July 1996.
- J.L. Roeder, J.F. Fennell, H.E. Spence, and W.J. Hughes, Statistical Model of Energetic Ion Distribution Moments in the Inner Magnetosphere, American Geophysical Union Fall Meeting, San Francisco, December 1996. (Abstract: *EOS*, 77, F600, 1996)